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# Safety Assessment for Explosives Risk (SAFER)
# Peer Review Report

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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# Safety Assessment for Explosives Risk (SAFER) Peer Review Report

**Dr. Leon D. Chapman, Chairman**
**System Sustainment & Readiness Technologies Department**
**P.O. Box 5800**
**Albuquerque, NM 87185-1176**

**Paul LaHoud, Consultant**
**16210 East Glenn Valley Drive**
**Athens, AL 35611**

**Olaf E. R. "Ross" Heimdahl**
**Naval Air Warfare Center**
**NWAC Code 4T4330D**
**China Lake, CA 93555**

## ABSTRACT

At the direction of the Department of Defense Explosives Safety Board (DDESB), a Peer Review Team was established to review the status of development of the risk-based explosives safety siting process and criteria as currently implemented in the software "Safety Assessment for Explosive Risk (SAFER)" Version 2.1. The objective of the Peer Review Team was to provide an independent evaluation of the components of the SAFER model, the ongoing development of the model and the risk assessment process and criteria. This peer review report addressed procedures; protocols; physical and statistical science algorithms; related documents; and software quality assurance, validation and verification. Overall, the risk-based method in SAFER represents a major improvement in the Department of Defense (DoD) approach to explosives safety management. The DDESB and Risk Based Explosives Safety Criteria Team (RBESCT) have made major strides in developing a methodology, which over time may become a worldwide model. The current status of all key areas of the SAFER code has been logically developed and is defensible. Continued improvement and refinement can be expected as implementation proceeds. A consistent approach to addressing and refining uncertainty in each of the primary areas (probability of event, consequences of event and exposure) will be a very beneficial future activity.

**July 2004**
**Version 1**

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# Acknowledgments

The Peer Review Team would like to thank everyone who participated in our Peer Review visit at APT Research, Inc. (APT) on February 3-5, 2004. Specifically, we want to thank all of the APT presenters who provided detail briefings and documentation on Safety Assessment for Explosives Risk (SAFER). Special thanks are due for Meredith Hardwick, Tom Pfitzer, Pete Yutmeyer and John Tatom from APT.

On the government side, special thanks are due to Dr. Josephine Covino and from the Department of Defense Explosives Safety Board (DDESB) and Mike Swisdak, Naval Surface Warfare Center, Indian Head Division, for their time and efforts in arranging, attending, and participating in our meeting.

# Safety Assessment for Explosives Risk (SAFER) Peer Review Report 2004

## 1 Executive Summary

At the direction of the Department of Defense Explosives Safety Board (DDESB), a Peer Review Team was established to review the status of development of the risk-based explosives safety siting process and criteria as currently implemented in the software "Safety Assessment for Explosive Risk (SAFER)" Version 2.1. The Peer Review Team members were subject-matter experts in the primary technical components of the SAFER model. Peer Review Team member's resumes are found at Appendix A.

The objective of the Peer Review Team was to provide an independent evaluation of the components of the SAFER model, the ongoing development of the model and the risk assessment process and criteria. This peer review addressed procedures; protocols; physical and statistical science algorithms; related documents; and software quality assurance, validation and verification. The peer reviewers looked at the status of open actions from the previous Defense Threat Reduction Agency (DTRA) peer review. The peer reviewers were not restricted from offering observations or findings outside the overall objective if it would benefit overall program development. The review considered the program management goal of "*Transparency, Clarity, Consistency, and Reasonableness"* (TCCR).

### 1.1 Summary

Overall, the risk-based method represents a major improvement in the Department of Defense (DoD) approach to explosives safety management. The DDESB and Risk Based Explosives Safety Criteria Team (RBESCT) have made major strides in developing a methodology, which over time may become a worldwide model. The current status of all key areas of the SAFER code has been logically developed and is defensible. Continued improvement and refinement can be expected as implementation proceeds. A consistent approach to addressing and refining uncertainty in each of the primary areas (probability of event, consequences of event and exposure) will be a very beneficial future activity.

The following major issues were addressed in some detail:

1. *Does SAFER adequately address and implement physical science models for the explosion effects and consequences for both personnel and structures?*

   **Findings**: The development of physical science algorithms represents widely accepted methods, and the subject-matter experts (SMEs) involved were highly qualified. Sound and defensible judgment was used in the assumptions and application of chosen analytical methods. For the range of applicability of SAFER 2.1, the physical science results are reasonable and the possible uncertainty addressed.

   **Areas for Improvement:** SAFER 2.1 is currently under further development for significantly closer ranges of application than assumed for the original science algorithms. These algorithms will require detailed review and modification to assure applicability at the expected close-in distances for newer code versions. Basis of science development (structural algorithms) can be better documented to improve understanding of basic assumptions and judgments. Sensitivity studies would be beneficial in the continued refinement of uncertainty. Debris modeling is largely derived from empirical data and will continue to benefit from additional data. Refinement in air blast for terrain and atmospheric effects for consequences of large events would be beneficial in the future.

2. *Does SAFER adequately address the probability of event?*

   **<u>Findings:</u>** The SAFER 2.1 code that deals with the probability of an event is a table lookup function. The "bins" in the probability event table were based on existing data over a 10-year period of similar events. The newer SAFER 3 code will add 5 years of explosive event data for a total of 15 years of historical explosive accident event data. The "bins" were formed with a team of experts who reviewed the historical accident data. This is a reasonable approach to determining the probability of an event.

   **<u>Areas for Improvement:</u>** It is recommended that parametric sensitivity studies be performed that bound the degree of uncertainty of each area. Those uncertainty results should then be used to determine a balanced development effort for each parameter including probability of event (Events), probability of effects given an event (Effects), and probability of a fatality given and event and effect (Exposures).

3. *Does SAFER adequately address and implement statistical science models in aggregating the risks, developing expected values, and estimating the uncertainty?*

   **<u>Findings:</u>** From our review of APT Research Inc. (APT) efforts to implement the proposed uncertainty guidance, it is our opinion that APT is doing a very credible job in implementing the uncertainty calculations as proposed by the previous Peer Review Team. The culmination of this new method for addressing uncertainty will become available when SAFER 3.0 is released. There have already been substantial improvements made in SAFER 2.1 that address uncertainty.

   **<u>Areas for Improvement:</u>** APT will have adequately addressed all of the uncertainty concerns by the previous Peer Review Team when SAFER 3 is released. APT will add analysis within SAFER 3 that adequately addresses the aleatory and epistemic mechanisms to cover and treat risks.

4. *Is SAFER supporting documentation adequate for the user?*

   **<u>Findings:</u>** The Peer Review Team reviewed key user documentation. Technical Paper 14 and the SAFER 2.1 user's guide were reviewed and the typical user training received. Technical Paper 14 is well laid out and addresses all elements of the application of the method. The user's guide is in general well developed and linked to the training. Instructors for the training were key members of the APT staff with strong knowledge of the development of SAFER.

   **<u>Areas for Improvement:</u>** The ability to trace the primary science in Technical Paper 14 and the user's guide could be improved. Technical memorandums are the next level of documentation and in general can benefit from a more complete and consistent capture of underlying assumptions and limitations. Likewise, the user's guide can be further developed to clarify application.

5. *Are the risk-based site plan process and criteria for Service and DDESB review and approval appropriate?*

   **<u>Findings:</u>** The risk-based site plan process and criteria for Service and DDESB review process were presented as part of the user training. The material presented was brief and generally at a top level. The opinion of the reviewers is that, based on the developmental nature of the process and the lack of existing precedent, the level of review and approval is justified.

**Areas for Improvement:** The end-user would benefit from a detailed example and/or submittal "template" provided as part of the user training and appended to the user's guide.

6. *Are the risk-based site plan process and criteria for Services and DDESB review and approval appropriately and clearly supported by DDESB policy?*

   **Findings:** The incremental nature of the implementation of risk-based method and current DDESB policy may slow the application and increase end-user frustration and confusion.

   **Areas for Improvement:** More complete and definitive policy demonstrating the future commitment to the method will improve implementation.

7. *Is the current approach to program management and cost schedule control adequate for the continued development and implementation of SAFER?*

   **Findings:** The Product Development Team (PDT) approach used by the RBESCT has been very successful in achieving a common vision among stakeholders and developers. It is sometimes difficult for the PDT approach to management to clearly frame requirements and measure progress.

   **Areas for Improvement:** We suggest some refinements of management to improve definition of requirements and allocation of resources planned and expended. The RBESCT would further benefit from central contract management and consolidation of multiple funding streams.

## 1.2 Conclusion

The DDESB through RBESCT has made significant progress in the development of a methodology for the rational implementation of risk-based explosives safety in the DoD. SAFER 2.1 is a well designed tool with capability for future modular improvement. Implementation of the proposed six-year plan will allow significant progress and benefits in explosives safety modeling using SAFER. The Peer Review Team has seen no "show stopper" issues. Rather, continued commitment to development and implementation over time will determine rate of progress.

# 2 Introduction

This report discusses the results of an independent peer review of the development and implementation progress of Safety Assessment for Explosive Risk (SAFER) Version 2.1. The SAFER model calculates risk in terms of the statistical expectation for loss of life from an explosives event. Three components are multiplied to estimate annual maximum probability of fatality ($P_f$) and the expected fatalities ($E_f$): (1) the probability of an explosives event ($P_e$), (2) the probability of a fatality given an event ($P_{f/e}$), and (3) the expected exposure of an individual ($E_i$). SAFER calculates personnel risk using the following equations:

$$P_f = P_e * P_{f/e} * E_i \qquad \text{to determine individual risk}$$

$$E_f = \Sigma(P_e * P_{f/e} * E_i) \qquad \text{to determine group risk.}$$

The review attempts to document a snapshot at this point in time of the maturity and consistency in level of development of key SAFER processes. It also suggests areas for consideration that will improve future independent efforts to benchmark the progress and credibility of the model and its implementation.

# 3 Scope

## 3.1 Background

The Department of Defense (DoD) Explosives Safety Board (DDESB) has coordinated the development of a model, SAFER, to address the risk associated with the full range of ammunition and explosives operations. Quantity-distance (Q-D) criteria that address the consequences of an accidental explosion or deflagration of ammunition and explosives (but do not quantify the risks) have been used in making safety judgments for 90 years. For the last 30 years, it has been recognized that Q-D (which considers only the explosives quantity, hazard class, and types of structures (to some extent) to determine a safe separation distance) could be improved upon by including other considerations such as the type of activity, number of people, building construction, and environment to assess the overall risk of the operation. Also, when Q-D standards cannot be met but there is a compelling reason for explosives storage or operations, there has not been a generally understood and accepted quantitative methodology for assessing the associated risks. Similarly, there has been no standard methodology for comparing risks of alternative layouts, whether or not Q-D standards can be met.

In 1997, the DDESB established the Risk Based Explosives Safety Criteria Team (RBESCT) to develop the risk-based approach for DoD to manage explosives siting. This approach has been computerized in the SAFER model, and it is now approved with supporting policy for use on a trial basis within DoD in assessing the risk associated with hazardous operations and storage of DoD ammunition and explosives.

## 3.2 Charter of the Peer Review

The charter of the Peer Review Team is to provide an independent assessment of the components of the SAFER model, the ongoing development of the model and the risk assessment process and criteria. This comprehensive peer review should address procedures, protocols, physical science algorithms, statistical science algorithms, software (SAFER 2), related documents and quality assurance, validation and verification. The peer review will also review the status of open actions from the previous Defense Threat Reduction Agency (DTRA) peer review. *The peer reviewers are not restricted from offering observations or findings outside the overall objective if it may benefit overall program development.* The review will also consider the program management goal of "*Transparency, Clarity, Consistency, and Reasonableness*" (TCCR).

The following questions will be addressed.

- Does SAFER adequately address and implement physical science models for the explosion effects and consequences for both personnel and structures?

- Does SAFER adequately address the probability of event?

- Does SAFER adequately address and implement statistical science models in aggregating the risks, developing expected values, and estimating the uncertainty?

- Is SAFER supporting documentation adequate for the user?

- Are the risk-based site plan process and criteria for Service and DDESB review and approval appropriate?

- Does the risk-based site plan process and criteria for Services and DDESB review and approval appropriate and clearly supported by DDESB Policy?

- Is the current approach to Program Management adequate for the continued development and implementation of SAFER?

The reviewers are not restricted from offering observations or findings outside the scope of the preceding questions. A final report of all finding and recommendations is expected at the end of the study.

# 4 Assessment of SAFER Code

## 4.1 Technical

When considered in the aggregate of what is trying to be accomplished with this code, the three major parameters are:

1. Probability of an event (Events)
2. Probability of effects given an event (Effects)
3. Probability of a fatality given and event and effect (Exposures)

SAFER uses two equations that are basically originated from this equation 1:

$$Risk = Likelihood * Consequences * Exposure \qquad (1)$$

SAFER uses this formulation to calculate the product of three components to estimate the annual probability of fatality, $P_f$, as shown in the following equation:

$$Risk = P_f = P_e * P_{f|e} * E_i \qquad (2)$$

The $P_e$ is defined as the probability that an explosives event will occur per potential explosion site (PES) per year. The $P_{f|e}$ is defined as the probability of fatality given an explosives event and the presence of a person. $E_i$ is defined as the exposure of one person to a particular PES on an annual basis.

A second measure associated with group risk is expected fatalities, $E_f$. This is defined as the summation of individual risks and provides expectancy or expected value (i.e., the average number of fatalities expected per year) as shown:

$$E_f = \sum_n (P_e * P_{f|e} * E_i) \tag{3}$$

It appears that the major development and work in terms of details of the SAFER code is in parameter 2. One might consider making the argument that detailed calculations of parameter 1 and 3 are lacking when compared to parameter 2. It is recommended that parametric sensitivity studies be performed that bound the degree of uncertainty of each area and those results be used to determine a balanced development effort for each parameter.

### 4.1.1 Probability of Event and Exposure

The first term of the risk equation is the probability of event, $P_e$. This term is used to assess the likelihood that an explosives event occurs. To incorporate the $P_e$ into SAFER, a $P_e$ matrix was developed using a compilation of historical explosives accident data from the U.S. Army, Navy, and Air Force.

The $P_e$ is a function of three parameters:

1. Activity at the PES (activity type)
2. Storage and transportation compatibility group (CG)
3. Scaling factors

The section of the SAFER 2.1 code that deals with the probability of an event might be characterized as a table lookup function. The “bins” in the probability event table were based on existing data that existed over a 10-year period of similar events. The newer SAFER 3 code will add five years of event data for a total of 15 years of historical explosive accident event data. The “bins” were formed with a team of experts who reviewed the historical accident data. This is a reasonable approach to determining the probability of an event.

### 4.1.2 Probability of Effects Given an Event

Historical implementation of explosives Q-D regulations based on empirical observations of accident results and test results provided only limited insight into the consequence of events. Implementation of a fast running software tool such as SAFER that quickly provides standardized, risk and consequence information to decision makers represents a significant advance in the DoD management of explosives safety. Credible and defensible physical science algorithms are critical to providing the decision makers with the best possible estimates of consequences of an explosive incidence at a given site. It is equally important that this science demonstrate, from a legal and regulatory perspective, reasonable standards of care and address public perception. Physical science effects to be considered include:

- Air blast
- Thermal
- Fragmentation and debris
- Building damage

#### 4.1.2.1 Air Blast

The air blast parameters' (pressure and impulse) values utilized by SAFER are estimated using Kingery-Bulmash equations. These algorithms have been validated and refined through more than 30 years of application and supporting test data. The principal technical experts supporting SAFER in the application of air blast algorithms are Mr. Michael Swisdak, Swisdak, Naval Surface Warfare Center, Indian Head Division, and Dr. Jerry Ward. Both are respected worldwide for their expertise in this field. Over the last 20 years, they have participated in DoD, North Atlantic Treaty Organization (NATO) and other international committees and supported numerous blast effects test programs. This has provided access to a large body of experimental data used to validate and refine simplified versions of the original Kingery-Bulmash equations. These updated algorithms have been incorporated in the current version of the Blast Effects Computer (BEC) developed by Mr. Swisdak and Dr. Ward for the DDESB. The BEC is used as the routine within SAFER to extract air blast data for subsequent human injury, structural damage and debris and analysis. The algorithms within the BEC provide the modifications of pressure and impulse for TNT equivalence and for weapon casing when present. The selected cased weapons have been validated through testing as "worst case" munitions in terms of fragmentation and are conservatively used to represent cased items with less severe effects. The BEC also provides pressure and impulse attenuation algorithms for a family of the most commonly used ammunition and explosive PES structures within the DoD. These attenuation modifications are derived from analysis of test data. The approach is well founded in extensive experimental data. It is important to understand that the air blast algorithms as utilized in the BEC are based on the *assumed environmental condition of blast wave reflection and expansion over a plane surface in a uniform standard atmosphere.* It should be noted that in the U.S and worldwide these boundary conditions are assumed and used in the application of all existing Q-D standards. Under these conditions, *the degree of uncertainty in air blast parameter prediction is small* (a few percent). This limitation is recognized within the air blast science community but not so well by others in the safety and management areas. It can contribute to significant variation in the air blast loading from actual large explosions, such as those noted after the PEPCON accident in Henderson, Nevada, in 1988.

#### 4.1.2.2 Thermal

Since SAFER "is designed to evaluate risks at large distances from the PES," thermal effects are likely included for completeness of the total method. Thermal effects are calculated by a quantity-distance factor and are used for Hazard Division (HD) 1.3 explosives (mass fire, bulk propellant). This factor is adjusted for the Exposed Site (ES) building type and the number of windows in the structure. Since the probability of fatality due to thermal effects are most likely to be low compared to blast or fragmentation in a major event at most distances, the approach used seems more than adequate. Only if a scenario is found in which a thermal effect is of dominant importance would refinement of the computational method be needed (for instance, mass storage of weapons designed to utilize thermal effects). There appear to be no current plans of development in this area for future versions of SAFER. Thermal codes are available elsewhere and could be utilized for improved calculations.

#### 4.1.2.3 Fragmentation and Debris

The creation of debris—primary steel fragments from explosive items, secondary chunks of concrete from the PES and ejecta from the ground— is a complex process the results of which are best characterized by statistics. Technical Paper 16, "Methodologies for Calculating Primary Fragment Characteristics," gives a thorough description of the standard methods (Gurney and Mott) used for estimating fragment distributions (mass and velocities) from naturally fragmenting bombs or warheads (with some discussion of preformed fragments). These methods are supported by experimental results. Extension of these methods to multiple (stacks) of munitions is discussed. Validation and improvement of the extension methods to multiple items will benefit from test programs.

The implementation of the methods for estimating primary fragment distributions in SAFER is to characterize a growing number of available weapon types by distribution described by bins of initial kinetic energies and maximum throw distances (essentially initial velocities). For a naturally fragmenting bomb or warhead, the fragments produced not only vary in mass and velocity, and therefore kinetic energy, but also in shape. Fragment shape affects the efficiency of flight through the air and penetration of barriers. These variations will cause scatter in test results. However, inevitable deviation of test results from the fairly straightforward SAFER calculations should be covered by the evolving uncertainty computations.

Fragment distributions from single bombs and warheads are characterized by mass, velocity and polar angle; so there is an orientation component. It might be expected that total debris from neatly stacked munitions might also have such a component. It might also be possible that the general direction of debris could depend on the location of the original donor to an event. Orientation of the PES to the ES is a part of the SAFER input. The "cloverleaf debris pattern" task has an improvement priority number of 7 (SAFER 3+). This is an area that may need to be revisited if any test data is found or developed.

The three improvement tasks for SAFER 3 with the highest priority or lowest level of difficultly concerning debris are: 1) the high-angle/low-angle split task; 2) the close-in, fly-through debris task; and 3) the crater ejecta issue task. In addition, a field storage (iso-container) PES option is reported as completed and ready for inclusion in SAFER. The debris issues raised in the review of SAFER 1 concerning the assumption of simultaneous detonation (step 4) and containment (step 12) have been designated as closed due to low probability of a scenario and consideration promised at a later date. Other debris issues appear to have been successfully resolved. Generally, any validating data that can be afforded would be valuable and should be documented.

#### 4.1.2.4 Building and Glass Damage

The analysis of structural response and consequently building damage is required to estimate serious injuries and fatalities resulting from air blast from explosions. Significant uncertainties exist not only in the air blast propagation but also in the resulting loading of a particular structure and finally in predicting the structure's dynamic response. As the load exceeds the structure's design capacity, deformation, debris and finally collapse lead to risks to building occupants. The expertise and judgment of the analysts in modeling these types of phenomena are extremely important in limiting uncertainty. The building damage model development team includes Mr. Jim Tancreto of the Naval Facilities Engineering Service Command (NFESC), Jon Chrostowski and Wenshui Gan of ACTA, Paul Wilde (formerly of ACTA and now of the Federal Aviation Administration) and David Begosian of Karagosian and Case. All of the team members are extremely knowledgeable engineers/analysts with extensive backgrounds in this field. They have been involved in similar ongoing work with the Air Force Range Commanders, NFESC, and DTRA. Analytical modeling by this team is expected to be highly credible if properly translated in the code development process. As discussed in the supporting documentation, three different approaches have historically been used to estimate building damage from air blast load and debris:

**Level 1 Methods –** Damage is related strictly to blast intensity (overpressure) without regard to duration based on observation of accident data or testing. This approach was common prior to the availability of fast running structural analysis codes. Most structural damage data from the 1940s through the 1970s was documented in this form. Little physics-based analysis was attempted to relate this data to injury or fatalities. Level 1 Methods were not utilized in SAFER 2.1 except as a means to validate other analysis or supplement expert opinion where analytical methods are limited.

**Level 2 Methods** – Recognize that structural response to air blast is dynamic and relates to both pressure and impulse (duration of the blast load). This approach is computationally intensive and requires use of appropriate computer codes and a knowledgeable analyst. Structural damage and glass breakage are based on simplified physics-based models that estimate response to both pressure and impulse. The analyst must develop criteria that can be used to relate structure response to level of building damage. From this point, injuries and fatalities of building occupants are related to the level of building damage and/or glass breakage. The translation of the resulting damage to injury or fatality requires expert judgment and grounding to actual data and has a much higher degree of uncertainty. Level 2 modeling is the basis for most of the structural damage algorithms in SAFER 2.1

**Level 3 Methods -** Structural damage or glass breakage is based on detailed models that estimate the dynamic response of structural elements and window components (e.g., time histories of deflection, stress, nonlinear behavior). After structural or glass failure, impulse-related debris models are used to track flying glass shards and/or wall and roof debris falling into the building. Human vulnerability models (for both blunt and penetrating objects) are then used to determine the probability of serious injury and/or fatality to occupants as a function of the mass and velocity of wall/roof debris and flying glass shards. This approach provides the most analytically complete approach but is computationally intensive and requires significant biomedical modeling with its additional uncertainty. Level 3 modeling has been utilized in the development of the glass damage algorithms

<u>Building Damage</u>. The SAFER 2.1 structure modeling strategy is derived from pressure-impulse (P-I) model methods. P-I models are considered to be Level 2 models. This approach has been used for structural response to air blast loading for many years and is widely accepted as a technique to simplify damage estimation. Depending on the degree of fidelity and validation with Level 3 models, they can be a suitable means to provide fast results over defined ranges of loading and response. The SAFER 2.1 P-I models were derived from an existing damage model "Facility and Component Explosive Damage Assessment Program" (FACEDAP), developed by the Corps of Engineers (1994). To simplify structural model development effort, as well as coding effort and complexity of user input, SAFER 2.1 utilizes a limited number of building structural configurations (15 buildings, 1 vehicle). In addition, the P-I response curves of these structures have been simplified from the FACEDAP approach which required development of many detailed elements of the building structure. In SAFER 2.1, multiple FACEDAP components were aggregated to whole wall and roof elements and subjected to many loadings oriented around and at varying distances from the structure. Then the damage for the wall facing reflected pressure and impulse, and all other walls loadings are averaged to develop a single P-I curve that represents the entire building. The damage criteria for SAFER P-I components are the same as FACEDAP and have been found to be generally conservative. Understanding limitations and uncertainty of this single value "smeared average" damage P-I curve is important. Because of the number of components summed in the models, an "average" P-I damage of 20% in SAFER may mean a damage level on the wall facing the explosion of 40%, while other walls may see less than 10%. The model "average" damage curves are then indexed to the incident pressure and impulse from the BEC model. This approach allows the siting of ES buildings by end-users to be based solely on distance from the PES, with no requirement to orient the exposed structure for a reflected loading. In addition, use of standard building sizes limits the requirement for users to develop extensive building structural information. The resulting single-value damage fraction is then related to the likelihood of injury through comparison with available data from explosive events, other models and the judgment of the analytical team. The ratio of fatalities-to-injuries likewise considers accident data and judgment. The analytical team attempted to validate the casualty and fatality relationships with numerous available explosive incidents and test program data for conventional explosions, nuclear tests and another advanced building damage code (ERASDAC). Results correlate reasonably well. SAFER coding then transforms the fatality estimates to a lognormal distribution to derive the final building fatality estimate. *It is uncertain why the lognormal transformation is used, and it would appear to add another factor of uncertainty to the results.* The reviewer was unable to determine if the overall degree of uncertainty associated with these simplified methods has been quantified or documented. The RBESCT may have judged that, for the relatively modest structure damage levels expected at the ranges under consideration in SAFER 2.1 (Public Traffic

Rout (PTR) and beyond), these uncertainties were small compared to uncertainties in other branches of the SAFER code.

Glass Breakage. Risk and consequences from glass breakage are known to be significant to distances in excess of twice current inhabited building distance standards. Based on substantial glass modeling by ACTA and to simplify and limit model complexity, end-user input and data collection workload, injury and fatality P-I diagrams were developed for nine representative window types (three sizes each of annealed, dual pane and tempered glazing) and for the passenger vehicle. Level 3 (physics-based) modeling techniques were used to develop the glass breakage, serious injury and fatality P-I diagrams. The Level 3 glass modeling is a very comprehensive approach. The analysis computes the response, breakage, trajectory and consequences of blast loading on the windows. It computes the response of the window using a single degree-of-freedom, nonlinear resistance function and accounts for uncertainty in critical input parameters using Monte Carlo method of underlying material properties. The response is compared against the strength of the window to determine breakage limits. The fragment size distribution is determined as well as the initial velocity profile across the window area. The trajectory of the shards thrown into the room is determined as well as whether the shards will impact a person within a defined exposure area. The final P-I diagrams do not represent the probability of breakage, serious injury and fatality of a single window pane, but rather the consequences averaged over all windows (front, side and rear) of a generic building configuration. This "averaging" approach requires the same cautionary awareness as mentioned earlier for averaging of structural P-I curves. The windows on the wall facing the event and subject to reflected pressure and impulse may give results substantially worse than the "average." The results of the window model can be adjusted through a simple scaling method to represent other smaller or larger buildings with more or less window area. A substantial effort was expended by ACTA to validate the glass modeling. Validation consisted of comparisons to test data and other model results. Historical evidence from accidental, experimental and other events was compared with modeling results. In addition, expert opinion surveys were also used. The effort in the development and validation of the glass model has been thorough and highly credible. However, it is expected that substantial additional data and refinement of methodologies from many government agencies as well as industry will occur in the next few years. This technology development should be tracked closely to integrate appropriate improvements.

### 4.1.3 Probability of a Fatality Given an Event and Effect

The probability of fatality given an event and effect is one of the most difficult parameters to develop. As mentioned previously, the correlation of fatalities to structural damage is largely based on empirical ratios of fatalities to injuries taken from observed events with similar building damage. Because the SAFER building damage is largely Level 2-based analyses, the development of these ratios is more subjective and uncertain than for the Level 3 methods (which still have a notable degree of uncertainty) utilized for the glass modeling. Increased use of Level 3 methods for structural damage prediction can refine the prediction of injuries and fatalities and result in physics consistent with the glass model methodology. It is understood that more-advanced Level 3 modeling of building damage and related injury and fatality is ongoing with other agencies. Efforts should be made to take advantage of this work to continue to improve the confidence in the model and reduce areas of uncertainty. However, given the use of single-point P-I damage index, there will still be a great deal of uncertainty in fatality estimation. Some parametric sensitivity studies would be valuable in quantifying these issues. Accurate fatality distribution for closer-scaled ranges contemplated in SAFER 3 and beyond will likely require models capable of addressing orientation and localized variation in ES building damage.

A summit with the NATO organizations was conducted for modeling assessment of explosives codes to compare model results from a common problem. The results presented to the Peer Review Team of this summit indicated that the SAFER code was provided more detailed analysis capabilities in almost every case. Similar results were obtained from all the models to the extent possible.

The annual exposure versus sequential operations needs some more attention. Migrating away from expert opinions to a more rigorous analysis is probably required in both the probability of an event and the association of fatalities. Some thought should be given to this area, and an improved normalization of risk calculation should be performed. For instance, the probability of an event might be correlated to the presence of workers and even to the number of workers. so that an hourly probability of an event is not the yearly probability divided by the number of hours in a year.

### 4.1.4 Uncertainty

The previous Peer Review Team was heavily involved in providing detailed guidance on how to add and calculate the uncertainty associated with SAFER detailed calculations. From our review of APT's efforts to implement the proposed uncertainty guidance, it is our opinion that APT is doing a very credible job in implementing the uncertainty calculations as proposed by the previous Peer Review Team. The culmination of this new method for addressing uncertainty will become available when SAFER 3.0 is released. There have already been substantial improvements made in SAFER 2.1 that address uncertainty. Currently, the uncertainty tree includes three major terms at the top and a total of 11 factors for the final calculation, with most of the detail in the effects part of the tree.

Given the current design of SAFER, the method by which APT is implementing these uncertainty calculations is adequate. In a more general way, one would expect uncertainty to be calculated using some form of multiple simulations (Monte Carlo) with random draws taken from distributions of the parameters involved in SAFER. To implement such a method would require a major restructuring of the SAFER architecture, and this Peer Review Team does not see the benefits that would be derived as necessary.

In SAFER 2.1, uncertainty is calculated outside of the basic model and does not have any affect on the average value. Correlations are not fully treated in SAFER 2.1 There is a post processing of data performed using the uncertainty tree to aggregate the risk.

In the SAFER 3 design, APT has built uncertainty calculations into the code that do affect the average value of risk. This work is based on cooperative efforts with DTRA Subject Matter Experts (SMEs), and the result defined in Dr. R.W. Mensing's paper dated 4 Nov 03. Correlations will be fully treated in SAFER 3. We believe that APT will have adequately addressed all of the uncertainty concerns addressed by the previous Peer Review Team when SAFER 3 is released. APT will add analysis within SAFER 3 that adequately covers the aleatory and epistemic mechanisms to cover and treat risks.

### 4.1.5 User Interface

In general, the user interface and amount of input data required by the user are very well done. There are a few places and terminology that we believe could be improved. A few minor title changes might be appropriate (e.g., "Scaling factors" might be changed to "Environmental factors"). It would seem that the input screens might be made more similar to the "User Settings for PES" screen to help the user better understand the inputs and the outputs. The outputs shown in the "User Settings for PES" screen are clearer for understanding the user inputs. Maybe the input screens can be constructed into categories similar to the output screens.

The outputs are definitely oriented toward a scientist, with notation as follows: 1.8e-10. Maybe one could provide a toggle capability between scientific and decimal notations. We realize this may be impractical when there are large (>10) exponents involved.

It would be more consistent if a descriptive message would appear to inform a new user that "D" is the default when the default "unknown" choice of compatibility group is selected. It might also be useful and re-assuring to a new user familiar with Q-D if a safe distance value based on the old method could be included in the PES printout at the end of input.

### 4.1.6 Limitations

#### 4.1.6.1 Protocol – Steps – Sequential

A protocol was defined and shown using SAFER in an evaluation of the Blount Island site. The protocol was basically a set of steps/locations that the SAFER analysis performed. An individual SAFER analysis was performed to account for transportation, loading, unloading, storage, etc. This approach was very elementary and needs to be automated in some fashion. The basic methodology (protocol) was shown for the Blount Island analysis. It is our belief that scenarios and the modeling of these scenarios (probably using simulation) is required for modeling and performing analysis of different scenarios/protocols. There should be a way to specify the scenario in detail. SAFER code needs to roll up and simulate (run) the code to assess a complete base with multiple scenarios.

#### 4.1.6.2 Applications

The risk-and-consequence analysis capabilities of SAFER provide a significant advance within the DoD for explosives safety management and siting. In addition, SAFER would have valuable application for installation and facility master planning, military construction (MILCON) programming and overall command visibility and readiness. The concept of TCCR is critical to the successful implementation and application of risk-based methods and SAFER. Risk-based methods are widely used by other government agencies in many forms. Risk-based decisions that have created public risk *or the perception of such risk* have been challenged by the public with competing approaches. As the risk-based methods in SAFER are more widely implemented, the underlying methods and algorithms will come under more scrutiny, including possible legal challenge. SAFER 2.1, as reviewed, has significant capability but at the same time is a work in progress, with many limitations to be addressed as planned in the RBESCT six-year plan. As each version of SAFER is implemented, the version of SAFER code in use, the training of end-users and some form of concise documentation should be maintained that captures the capability and limitations of the version. This would include source algorithm maturity, uncertainty and any future activity to improve or refine it. The released and approved version of SAFER should be coded to prevent users from entering input inconsistent with the limitations of the underlying algorithms. Some science limitations which could be made more visible are listed in Section 4, Improvements. While the current science limitations are addressed by the uncertainty bounding in SAFER 2.1, it is noted that nearly all of the uncertainty upper bound estimates are from "expert elicitation." Expert elicitation is often challenged; and the long-range desire should be to better quantify these factors with some type of improved analytical method, sensitivity study or testing. Acknowledging and addressing these concerns are consistent with the goal of TCCR.

The RBESCT is complimented on the amount of effort it has expended in attempting to document the development of SAFER. In reviewing this extensive library, many of the issues raised during this review along with apparent courses of action have been surfaced by the RBESCT at different times. As development progresses, it is believed that a more concise history of each underlying methodology, algorithm, or placeholder would be greatly beneficial to increasing the TCCR objective and to expedite and improve the ease of any future reviews. It appears that the technical memorandum process is a suitable mechanism for this purpose. However, the content of the current versions of these memoranda are not in a format nor do they include all of the content necessary to track the development, assumptions, uncertainties and future improvement goals.

### 4.1.7 Inputs/Outputs/Design

The basic design of SAFER is adequate for what the code has been designed to address. Minor improvements in terminology could be made to the existing input screens and have been suggested above. The outputs seem to be well organized and presented correctly. The calculations and design within SAFER are very efficient. We applaud the SAFER design team with a job well done in keeping the inputs simplified and the outputs well organized. The detailed physics calculations appear to be well thought-through and provide meaningful results. The SAFER design somewhat limits the ability to wrap a simulation around SAFER to address multiple evaluation points (protocols) and perform random draws from distribution of parameters for calculations of uncertainty. The previous peer review team recommended a Monte Carlo approach. SAFER 3 uses an analytical based model formulated by a previous peer reviewer for uncertainty that replaced the Monte Carlo method.

A scenario capability (protocol) method needs to be developed to allow the user to describe a base storage for explosives and movement of explosives into and out of storage. In addition, the capability to address different environmental conditions (wind, rain, humidity, etc.) and their effects on the SAFER calculations should be considered. Conceptually, multiple runs of SAFER would need to be encapsulated for covering a complete scenario or set of scenarios (protocols) for a base analysis. Ideally, the user should be able to describe the scenario or set of scenarios; and the complete analysis would be performed by SAFER and summary results presented for each major area of concern.

### 4.1.8 Certification/Validation/Verification/Commercialization

The SAFER code would seem to have applications for base evaluations in support of programs like Guardian (which is directed at evaluation of chemical, biological, nuclear, and radiological threats on all of the government facilities in the U.S. and overseas). From a government point of view, there seems to be an oversight by the DDESB on moving toward a formal certification of the SAFER code. This would include the need for software validation and verification (V&V) of the SAFER code. The Peer Review Team highly recommends that it is time to formally approve the SAFER code for appropriate explosives risk evaluations. What we are suggesting is that it is time to take the next step in a formal process to properly certify the SAFER code. It appears to us that SAFER can easily meet all of the requirements of a formal V&V review and approval. It is our belief that the SAFER code deserves and should be formally certified for government use.

The other related area is commercialization. The Peer Review Team did not see or hear of any plan to commercialize the SAFER code. We believe that commercialization of SAFER should be considered and a plan developed with a schedule to move toward this objective. Consideration of potential users and demand for SAFER both in the U.S. and NATO communities should be considered as part of this process.

## 4.2 <u>Management</u>

### 4.2.1 Software Management/Development

The methodology used in the SAFER software development activities was very structured. The controls associated with tracking changes and document library check-ins are an excellent method to manage software development.

The SAFER documentation is excellent. A number of detailed documents describing the SAFER code have been developed and provide an excellent foundation and resource of information. In addition, a number of SAFER courses have been presented along with the detailed supporting documentation. The SAFER code documentation provided to the Peer Review Team was outstanding.

### 4.2.2 Program Management

#### 4.2.2.1 APT

APT has responded to customer needs in a very professional manner, with excellent and knowledgeable staff working on SAFER. APT has demonstrated a high degree of commitment to the RBESCT and successful program management. In particular, the APT role in facilitating team building and consensus among DoD stakeholders has been an important factor in continued advancement of the risk-based methodology. On the administrative side, the multiple contract vehicles, piecemeal availability of funds, limited project task scheduling, and requirements creep all contributed to challenges in efficient performance of production work such as code development and validation.

#### 4.2.2.2 Government/Sponsors

The government participation on the RBESCT has been notable in terms of the depth and breadth of knowledge of DoD explosives safety policy, regulation and explosive effects and structural response science. The government science personnel have provided critical, long-term expertise that was successfully leveraged through contractor support. However, it appears the government contribution to the team likewise suffered by the nature of the funding stream, the "time and material" nature of the project planning and scheduling, and the difficulty in achieving a consistent contracting method.

### 4.2.3 Vision for SAFER

The RBESCT-proposed future development recommendations for Risk-Based Explosives Safety Methods and SAFER were reviewed as presented in the April 2003 Vision Paper. A vision statement is normally a very brief and to-the-point summation of the expected future state of an organization, product, or service. For example, the vision statement for SAFER and risk-based methods might be as noted in the body of the paper as:

> "*The ultimate goal is to have a suite of explosives safety risk assessment tools that is not only adopted by DoD but is recognized and accepted by the worldwide explosives safety community*.**"**

The vision paper contains this theme but also appears to be intended to be a short tutorial and background paper on the development and future of SAFER and a plan on how the future vision can be achieved. Two key areas for explosives safety have been identified. The first is associated with risk management and the second is associated with siting. The goal for risk management is to increase safety by understanding and lowering risk. This potential use is envisioned to have a wide application among safety personnel managing explosives risks. A significant benefit of this type of assessment is the insight into the driving factors of risk gained by the practicing safety personnel. These insights are often not intuitive and are not at all evident when applying the current Q-D method. The goals for siting are to provide a high degree of safety to personnel and meet operational requirements in a consistent manner. The current Q-D approach to siting is acknowledged to be very limited in these key areas.

The direction of the DDESB and the accomplishments of the RBESCT in the development of SAFER have addressed both of the areas above. However, the reviewers believe that the application of risk management and siting using SAFER is going to be significantly more complex for safety personnel and management to apply and interpret. Key to implementation of the method is criteria acceptable to the stakeholders (DDESB, military Services, etc.). Development of implementing policy appears to be very cautious. Initial criteria has been developed addressing the protection level for an individual (public or worker). These criteria form the foundation for a future complete set of criteria that would also provide protection for workers, and collective risks for groups. Other measures, such as injury or asset damage and mission impact (consequence analysis), are expected to be in demand in the future. Refinements of criteria are expected before the end of 2004, to include group risk criteria.

The modular design of SAFER provides a capability to easily tailor a version of SAFER for multiple uses. SAFER can also provide a capability for explosives risk assessments for use by commanders in making peacetime, deployment, theater of operations, and other explosives safety and force protection decisions. It can be extended to address transportation, off-post hazards to the public, commercial facilities deployments, and transformation initiatives. SAFER has additional capability not noted by the vision paper in the area of facility and installation master planning and in MILCON programming. With some modification, it may also be valuable for unexploded ordnance cleanup, which could result in significant savings in program life-cycle remediation cost. The reviewers believe that SAFER is maturing technically in a timely manner to meet the objective of the suggested vision statement. Development of an implementing service policy, a precedent for liability, and public acceptance will all be controlling factors in the degree and rate of acceptance of the SAFER code.

Efforts to initiate many of the other potential capabilities outlined in the vision statement have not begun and strategies to do so are not clear. These other applications are beyond the charter of the RBESCT and would require additional program management direction and funding.

#### 4.2.3.1 User

The current vision for SAFER application is focused on the safety professional as the end-user. There are many other possible users, as suggested above. An approach for including other users for applying SAFER would be useful. The training taken by the peer reviewers indicates that a higher level of safety training and knowledge than some of the end- users will have (i.e., “Airman Snuffy”) is required. End-users will need to develop experience (with some oversight) using the SAFER code before they can be expected to be independently competent. Evolving policy and precedent in application will continue to be sources of problems and frustration for end-users.

#### 4.2.3.2 Standard Tool for DoD Explosives Safety Siting Work

The vision statement and six-year plan indicate that the long-range goal is for SAFER to be the standard tool for all DoD explosives safety siting. The implementation plan and schedule to achieve this goal are not clear and appear to be uncertain at this time.

#### 4.2.3.3 There is Not a Clear and Binding Policy On How/When to Use SAFER

Continued, expanded use of SAFER will depend on how soon DDESB and the Services develop clear and binding policy. Based on the approval process presented in the SAFER 2.1 training, some observations are offered:

- Application of the policy letter is difficult to translate into a detailed plan.
- The approval process flow chart is excellent but at a high level.
- Data requirements for a submittal are formidable and only described at the summary level without detail of an acceptable format and content.
- A well structured template and associated example could be developed and provided in the user manual and utilized as a class example during training.

## 4.3 Cost and Management

The RBESCT appears to function as a Product Delivery Team. This approach has allowed the team great flexibility, maximized cross-functional communications and increased consensus building among the stakeholders. A great deal of productive work has been accomplished in this manner. However, the generalized objectives and frequent changes that result from this approach appear to make it difficult to clearly define requirements, plan and allocate work performed against specific work items and the related cost. A substantial amount of effort has been expended in Activity 5 (Team support, Meeting/Panel preparation, attendance, minutes; Consensus building) as shown in Table 1 below.

**Table 1 SAFER Expenditures by Activity**

| | | Calendar Year | | |
|---|---|---|---|---|
| | Activities | 2003 | 2002 | 2001 |
| 1 | Policy Development | 20% | 18% | 15% |
| 2 | Scientific Algorithms | 24% | 24% | 26% |
| 3 | Uncertainty Algorithms | 18% | 13% | 6% |
| 4 | Software Development | 15% | 21% | 37% |
| 5 | Team support; Meeting/Panel preparation, attendance, minutes; Consensus building | 20% | 21% | 15% |
| 6 | Contract Administration | 3% | 2% | 1% |

% denotes percentage of funding spent on each activity.

It is not clear to an outside observer that this effort can be delineated from the production work such as software and science algorithm development and science testing. A significant amount of funding has been expended over the last six years, and an equally large amount is planned for the next six. As the program becomes more visible, it can be expected to receive more scrutiny for achievement versus expenditures. We believe that Activity 5 needs to be more clearly defined versus the software and algorithms development activities. It is believed that the program would benefit by a more structured approach to work planning, linked to the six-year plan and budgeted to specific work breakdown structure (WBS) elements. A relatively simple project network breakdown to two or three levels would probably be adequate and would more clearly defend progress against funding. It would also be beneficial to program management in justification of funding requests to fund providers. A simple Network Analysis Schedule (NAS) tool such as Microsoft Project would be adequate. It is understood that work requirements would change; and revision to the baseline WBS is easily accomplished, providing a valuable audit trail.

## 4.3.1 Contract Management Approach

The RBECT development of SAFER over the last six years has been accomplished through as many as five or more funding sources, which include the DDESB, Army, Navy, Marine Corp and Air Force. Each source apparently provides a separate fund cite through a variety of contracting tasks or mechanisms. This funding was managed as a time and materials (T&M) contract effort. This makes tracking of expenditures against activities difficult as well as limiting program management visibility on work progress. It is not clear why all contributors could not provide direct funds to a single contracting office for management by a single contracting officer and contracting officer's technical representative (COTR). This, along with a resource-loaded NAS as suggested in the previous section, would greatly improve overall management and documentation of work performed.

### 4.3.1.1 Requirements Definitions

Activity 5 in Table 1 seems to be a separate activity from a normal software development project. If this activity is necessary among the sponsoring organizations, then maybe it should be considered as a stand alone and separately funded project. We believe the current approach for management of requirements has provided ill-defined requirements for APT and its software development team.

### 4.3.1.2 The Product Development Team (PDT)

The PDT approach utilized by the RBESCT has been very successful in developing a common vision, stakeholder buy-in and leveraging of the special skills and expertise of the government and the contractor.

The limitations on the PDT approach to management are typically in program management discipline and development of clear and measurable requirements. The review team has observed these same elements could be improved in future development efforts for SAFER. Without clearly stated objectives, requirement creep is common. The historical evolution of SAFER requirements appears to reflect the "fuzzy" nature of the PDT approach to software development, science, uncertainty, risk, etc.

# 5 Recommendations for Improvements

## 5.1 <u>Technical</u>

### 5.1.1 Probability of Event and Exposure

The three major parameters within SAFER are:

1. Probability of an event (Events)
2. Probability of effects given an event (Effects)
3. Probability of a fatality given and event and effect (Exposures)

It appears that the major development and work in terms of details of the SAFER code are in parameter 2. Currently, the detail calculations of parameter 1 and 3 are lacking within SAFER when compared to depth of calculations of parameter 2. It is recommended that parametric sensitivity studies be performed on the P(e) and exposure that bound the degree of uncertainty of each area and that those results be used to determine a balanced or appropriate development effort for each parameter.

### 5.1.2 Probability of Effects Given an Event

#### 5.1.2.1 Air Blast

The DDESB vision appears to be for SAFER to be the primary future tool for site plan assessment and risk management. It can be expected that SAFER would be used for the siting of a range of explosive quantities, from relatively small (less than a hundred pounds of explosives) to very large quantities (up to 5 million pounds of explosives). For large detonations, local atmospheric conditions and terrain can significantly alter the predicted attenuation of air blast with distance. Factors that contribute include local wind variations, atmospheric focusing and terrain. These variations have been recognized for large-scale explosive and nuclear test events and for missile and spacecraft ranges for launches. However, they have been historically ignored for Q-D regulation of "static" storage or handling. Long-term development of SAFER should consider when and how to address these variations for large-quantity situations. For example, sensitivity of air blast contours to local wind rose variations by month might be accommodated as part of initial risk management activities for very large quantities. Estimating air-blast modification from atmospheric variation and terrain is not considered for site plan approval but in the future might be addressed through parametric sensitivity studies of consequence analysis. For the near term, the RBESCT should begin to formulate criteria for such adjustments in parameters and consider suitable implementation methods and policy. For approved versions of SAFER, it is recommended that limitations on applications in areas of rapidly varying terrain should be documented in user's guides and incorporated in training.

The empirical algorithm currently utilized to predict progressive damage and eventual destruction of the PES can be significantly affected by gas pressure, venting rates, volume, strength and proportions of the PES storage structure. These effects will be most noticeable for closer-in exposures (less than scaled range of 9) and for PES quantities within an order of magnitude of the 100% destruction quantity. The uncertainty in this algorithm is not believed to be significant for PES explosive quantities significantly larger than the 100% destruct value at the scaled range of application of SAFER 2.1. For closer-scaled ranges, additional validation of the algorithm is suggested.

#### 5.1.2.2 Thermal

Since the probability of fatality due to thermal effects is most likely to be low compared to blast or fragmentation in a major event at most distances, the approach currently used in SAFER seems more than adequate. Only if a scenario is found in which a thermal effect is of dominant importance would refinement of the computational method be needed (for instance, mass storage of weapons designed to utilize thermal effects).

#### 5.1.2.3 Fragmentation and Debris

Fragment distributions from single bombs and warheads are characterized by mass, velocity and polar angle; so there is an orientation component. Orientation of the PES to the ES is a part of the SAFER input. The "cloverleaf debris pattern" task has a development improvement priority of 7 (SAFER 3+). This is an area that may need to be revisited if any test data is found or developed.

Three of the improvement tasks for SAFER 3 with the highest priority or lowest levels of difficultly concern debris are: 1) the high-angle/low-angle split task; 2) the close-in, fly-through debris task; and 3) the crater ejecta issue task. Generally, any validating data that can be afforded would be valuable and should be documented.

#### 5.1.2.4 Building and Glass Damage

It is suggested that a parametric sensitivity study be performed to estimate the range of uncertainties in the simplified underlying structural response models. In addition, the available structures may not be suitable to represent some classes of structures and may seriously underestimate the risk of collapse and casualties for low-pressure, high-impulse loading. Examples are gymnasiums, auditoriums and aircraft hangers. Such structures are commonly found on DoD installations and often in nearby communities. These structures are sensitive to significant damage at scaled ranges of K80 or more. They also tend to have the potential for high concentrations of occupants and significant consequences given an event. The use of a single P-I index for a structure also has limitations for lower charge weights. When the span of a structure becomes a significant percentage of the range, the P-I damage index from the front face to the rear may vary by three orders of magnitude. It appears that for structure dimensions less than 10% of the range, the variation is acceptable. A sensitivity study could resolve the range of variation for damage and resulting $P_{f/e}$. For other situations where the loading gradient across the structure is significant (scaled ranges << 24), structure orientation and damage/injury/fatality specific to reflected wall, sidewall and rear wall should be considered.

The SAFER 2.1 segregation of structures into square feet groups (<5000, 5000<20,000, >20,000) is not consistent with the development of the structural models in Appendix G of the user's guide (2500, 10,000, 40,000). This brings into question the fidelity with regard to the underlying assumptions used by ACTA in model development. No explanation could be found to clarify the reason for the change or the associated uncertainty.

The description of the structure types in Appendix G, SAFER User Manual, is sparse and does not make clear the underlying assumptions/limitations with the simplified models. For example, many building types do not identify roof support assumptions (i.e., interior columns or walls and associated span lengths or damage criteria for P-I development). It is suggested that Appendix G be revised to provide a much more detailed background on the structure types and the limitations within the context of the SAFER software evolution.

The development and modification of science algorithms within SAFER are clearly an ongoing process. SAFER 3.0 is already well under way and will extend the range and application of the tool to much closer ranges. Many of the algorithms which were judged to be reasonable for SAFER 2.1 have a great deal more uncertainty for scaled ranges much closer than K18. It is believed by the review team that more verification is required to confirm the extension of the SAFER 2.1 science algorithms. The concerns are summarized as shown in Table 2 below.

**Table 2 SAFER Concerns**

| SAFER SCIENCE ISSUES | METHOD | VALIDATION | | COMMENTS |
|---|---|---|---|---|
| | | RANGE > K18 | RANGE <<K18 | |
| PES Destruction | Empirical Data | Good | Limited | Lower Net Explosive Weight (NEW), Partial Destruction Fidelity |
| PES Dynamic Mass Dist | Empirical Data | Acceptable | Limited | Improved Level 3 Analysis, Test Data |
| PES Airblast Modification | Empirical Data | Good | Limited | Lower NEW, Shock Complexity, Gas Pressure |
| PES Debris Blocking | Empirical Data | Acceptable | Limited | Needs Better Science, Test Data |
| PES Crater Ejecta | Empirical Data | Limited | Limited | Better Science, Test Data |
| PES Ground Shock | N/A | Acceptable | Needed | Requires Consideration |
| ES Wall Damage | P-I Level 2 | Good | Limited | Improved Level 3 Analysis, Test Data |
| ES Collapse & Beyond | N/A | Acceptable | Needed | Improved Level 3 Analysis |
| ES Blocking Factor | Analytical 2 | Acceptable | Limited | Improved Level 3 Analysis, Test Data |
| ES Airblast Modification | Analytical 2 | Acceptable | Uncertain | Improved Level 3 Analysis, Test Data |
| ES Glass Model | P-I Level 3 | Good | Uncertain | Improved Level 3 Analysis |
| ES Glass % Limits | Expert Opinion | Marginal | Uncertain | Restrict Possible Area Choices |
| ES KE Penetration Res | Empirical Data | Marginal | Uncertain | Kinetic energy (KE) Relationship To Area/Mass -Test Data |
| $P_{f/e}$ Independence | Analytical 2 | Acceptable | Uncertain | Close-in-Time Dependence Overlap |
| ES Building Type Validity | Analytical 2 | Limited | Uncertain | Address Very Long Span Structures |
| $P_{f/e}$ Mechanism | Analytical 2 | Acceptable | Uncertain | Translation Sensitivity of Probability Density Function (PDF) Method |

### 5.1.3 Probability of a Fatality Given an Event and Effect

Accurate fatality distribution for closer-scaled ranges contemplated in SAFER 3 and beyond will likely require level 3 science models capable of addressing orientation and localized variation in ES building damage.

The annual exposure versus sequential operations needs more attention. Migrating away from expert opinions to a more rigorous analysis is probably required in both the probability of an event and the association of fatalities. Some thought should be given to this area, and an improved normalization of risk calculation should be performed.

### 5.1.4 Uncertainty

The Peer Review Team is satisfied that APT has adequately addressed all of the uncertainty concerns addressed by the previous Peer Review Team when SAFER 3 has been released. APT will add analysis within SAFER 3 that adequately covers the aleatory and epistemic mechanisms to cover and treat risks.

### 5.1.5 User Interface

A few minor title changes to the user interface screen would be appropriate (e.g., “Scaling factors” might be changed to “Environmental factors”). The input screens should be more similar to the “User Settings for PES” screen to help the user better understand the inputs and the outputs.

### 5.1.6 Limitations

User input for building floor areas appears to have a number of issues that the reviewers did not understand. As reviewed, it is possible for users to enter building floor areas for up to 99,999 square feet for any size building (<5000, 5000<20000, >20000). This seems to be totally inconsistent with the analytical assumptions used to develop the building size groups. It also has the potential to allow a user to believe he is addressing all damage concerns by simply using the floor area he feels is appropriate without realizing the floor area only affects the glass risk and not the building structure type. Thus, probability of building damage and horizontal and vertical debris damage may all be inappropriate for the floor area/building in question. In addition, the damage probabilities at the boundaries of building groups do not agree. For example, the probability of building damage for a 20,000-square-foot building in the 5000<20000 group is not the same as the damage for the same building in the >20000 group. Is this because the building damage is based on the upper bound of the group type? If so, that should be made clear. However, Appendix G (“ACTA Structures Data”) of the user’s guide defines a 40,000-square-foot large structure class, not 99,999. There is no comment in the criteria suggesting this size can be extrapolated up to the 99,999 limit now allowed in the user input and used for glass damage. Some other comments on Technical Paper 14 and the SAFER user’s guide include:

- Technical Paper 14 and the user’s guide should consistently define how the user inputs range to the ES (e.g., center of PES to center of ES, or near edge to near edge).
- The narrative in the user’s guide and Technical Paper 14 describing the floor area should be amplified to make user aware of the purpose and limitation of the term.
- The description of the percentage glass area should be amplified to make it clear that it is related to the entered floor area not the building group size.
- Clarify what the damage $P_{f/e}$ for each building size is. Is it the damage at the upper size limit for each structure group?
- Likewise, clarify what the horizontal and vertical debris damage are based on. Is it the upper bound of building size?
- Review of Appendix G, page G-1 provides a very brief description of recommended user decisions, which seem confusing. This wording could be clarified regarding significance of the wall parameters and also the relationship of the floor area entry to the building types provided.

### 5.1.7 Inputs/Outputs/Design

The basic design of SAFER is adequate for what the code has been designed to address. Minor improvements in terminology could be made to the existing input screens and have been suggested. A scenario capability (protocol) or sequence of operation method needs to be developed to allow the user to describe a base storage for explosives and movement of explosives into and out of storage. In addition, the capability to address different environmental conditions (wind, rain, humidity, etc.) and their effects on the SAFER calculations should be considered. Conceptually, multiple runs of SAFER would need to be encapsulated for covering a complete scenario or set of scenarios (protocols) for a base analysis. Ideally, the user should be able to describe the scenario or set of scenarios and the complete analysis would be performed by SAFER and summary results presented for each major area of concern.

### 5.1.8 Certifications/Validation/Verification/Commercialization

From a government point of view, there seems to be an oversight by the DDESB on moving toward a formal certification of the SAFER code. This would include the need for software V&V of the SAFER code. The Peer Review Team highly recommends that it is time to formally approve the SAFER code for appropriate explosives risk evaluations. It is our belief that the SAFER code deserves and should be formally certified for government use.

The other related area is commercialization. The Peer Review Team did not see or hear of any plan to commercialize the SAFER code. We believe that commercialization of SAFER should be considered and a plan developed with a schedule to move toward this objective. Consideration of potential users and demand for SAFER both in the U.S. and NATO communities should be considered as part of this process.

## 5.2 Management

### 5.2.1 Software Management/Development

The methodology used in the SAFER software development activities was very structured and impressive in terms of software development approaches. The controls associated with tracking changes and document library check-ins are an excellent method to manage software development. We strongly recommend the continuation of the current APT methods used in prior SAFER development.

### 5.2.2 Program Management

#### 5.2.2.1 APT

The multiple contract vehicles, piecemeal availability of funds, limited project task scheduling, and requirements creep all contributed to challenges in efficient performance of production work such as code development and validation. This cannot be fixed by APT but needs addressing by the sponsors.

#### 5.2.2.2 Government/Sponsors

It appears the government contribution to the team suffers by the nature of the funding stream, the “time and material” nature of the project planning and scheduling, and the difficulty in achieving a consistent contracting method.

### 5.2.3 Vision of SAFER

The reviewers believe that SAFER is maturing technically in a timely manner to meet the objective of the suggested vision statement. Development of more definitive DDESB implementation plan and service policy, a precedent for liability and public acceptance will all be controlling factors in the degree and rate of acceptance of the SAFER code. There are also other beneficial applications of SAFER within DoD which should be explored.

#### 5.2.3.1 User

There is a broad diversity of safety experience in end users for SAFER. Refinement of training materials and objectives for end users can be beneficial. An improved definition and training requirements for each type of user should be developed.

#### 5.2.3.2 Standard Tool for DoD Explosives Safety Siting Work

The Vision Statement and 6 year plan indicates that the long-range goal is for SAFER to be the standard tool for all DoD explosives safety siting. The implementation plan and schedule for this is not clear and appears to be uncertain at this time.

#### 5.2.3.3 There is Not a Clear and Binding Policy On How/When to Use SAFER.

Continued, expanded use of SAFER will depend on how soon DDESB and the Services develop clear and binding policy. As discussed in Section 4.2.3.3 continued improvement in application of policy will be beneficial.

## 5.3 Cost and Management

The generalized objectives and frequent changes that result from the PDT approach to management make it difficult to clearly define requirements, plan and allocate work performed against specific work items and the related cost. The SAFER software development costs are misleading when quoted in the aggregate cost. Management, consensus should probably be managed as separate contract elements.

The reviewers believe that the program would benefit by a more structured approach to work planning, linked to the six-year plan and budgeted to specific WBS elements. A relatively simple project network breakdown to two or three levels would probably be- adequate and would more clearly defend progress against funding. It would also be beneficial to program management in justification of funding requests.

### 5.3.1 Contract Management Approach

The RBECT development of SAFER over the last six years has been accomplished through as many as five or more funding sources, which include the DDESB, Army, Navy, Marine Corp and Air Force. It is recommended that all contributors provide direct funds to a single contracting office for management by a single contracting officer and COTR.

#### 5.3.1.1 Requirements Definitions

Activity 5 in Table 1 seems to be a separate activity from a normal software development project. If this activity is necessary among the sponsoring organizations, then one should consider a separately funded project for this activity. We believe the current approach for management of requirements has provided ill-defined requirements for APT and its software development team.

#### 5.3.1.2 The Product Development Team (PDT)

The PDT approach utilized by the RBESCT has been very successful in developing a common vision, stakeholder buy-in and leveraging of the special skills and expertise of the government and the contractor. The limitations on the PDT approach to management are typically in program management discipline and development of clear and measurable requirements. Without clearly stated objectives, requirement creep is common.

It is suggested that a matrix of proposed objectives be developed for each major area of the SAFER methodology. Each matrix should rank-order the priority of the activities to be considered. A unified matrix which prioritizes requirements against funds can then be developed and ranked by the RBESCT. This would drive the near-term focus for requirements.

# Appendix A:  Biographical Sketches

## Peer Reviewer – Chairman – Dr. Leon D. Chapman

**Name:** Dr. Leon D. Chapman
**Address:** P.O. Box 5800, MS 1176 Sandia National Laboratories, Albuquerque, NM 87185-1176
**Phone No:** 505-284-9631 Cell: 505-263-6030
**E-Mail:** LDChapm@sandia.gov

**Present Employer:** Sandia National Laboratories

**Highlights:** Dr. Chapman has served as the Demand Activated Manufacturing Architecture (DAMA) Laboratory Project Manager at Sandia National Laboratories since 1994. He served as the Project Manager on the Industrial Waste Reduction Program for 4 years. During his 20 years experience at Sandia, he has been involved in areas of demand activated manufacturing, electronic marketplace, safeguards and security, environmental problems, expert systems, modeling, databases, computer systems, and systems analysis.

During his 5 years at BDM, Dr. Chapman was a Senior Executive/Vice President of Special Technologies and was responsible for a variety of software development and automated manufacturing system development. His responsibilities included the development of special technologies that support the rapid prototyping and development of software for computer integrated manufacturing projects. This includes the use of Computer-Aided Systems Engineering (CASE) tools for automation of software development to enhance software productivity, graphics work stations, artificial intelligence tools, and decision support using expert systems.

Dr. Chapman has developed several simulation models of manufacturing facilities at Caterpillar, FORD, and other commercial facilities. These models have been used for planning and improvements to both existing and planned manufacturing lines.

At the University of Alabama, Dr. Chapman taught graduate and undergraduate courses in computers, systems analyses, numerical analysis and simulation. Global modeling in the systems dynamics area was a primary area of responsibility.

Dr. Chapman was a design engineer of electronic systems for the Geophysical Equipment Division with Continental Oil Company. Amplifiers, correlators, data reduction, and complete field systems were designed and tested. Integration of the electronics into electromechanical systems was required.

He served two years in the U.S. Army, Air Defense Artillery. His highest rank obtained was a Captain.

**Past Employment:** BDM International, Senior Executive/Vice President, Special Technologies, 1985 to 1990
Sandia National Laboratories, Division Supervisor, 1974 to 1985 & 1990 to 2001, 2003 - present
Avistar Corp, Chief Technologist, 2001-2002
Computer Science & Operations Research, University of Alabama, Assistant Professor, 1971 to 1974.
Center for System Science, Oklahoma State University, Research Assistant, 1968 to 1971.
U.S. Army, Captain, 1964 to 1966.
Technical Institute, Oklahoma State University, Instructor, 1967 to 1969.
Continental Oil Company, Design Engineer, 1962 to 1969.

**Education:** Ph.D., Electrical & Computer Engineering, Oklahoma State University, 1971 M.S., Electrical & Computer Engineering, Oklahoma State University, 1968 B.S., Electrical & Computer Engineering, Oklahoma State University, 1964.

Civic and professional activities, awards etc.: Dr. Chapman was a Professional golfer during 1990-1997 and played on the Senior PGA Tour in his spare time. As an amateur in 1998, he qualified and played in three U.S. Senior Opens.

**Relevant Recent Publications:**
Dr. Chapman has over 150 publications

## Peer Reviewer – Paul LaHoud

**Name:** Paul LaHoud
**Address:** 16210 East Glenn Valley Drive, Athens, AL 35611
**Phone:** 256-232-9121 Cell 256-777-9149
**E-Mail:** PL9121@aol.com
**Present Employer:** Self –Employed

**Duties or Job:** Consultant- Blast effects, explosives safety, design of blast resistant facilities, damage assessment,

**Highlights:** Chief of Design, Huntsville Center Corps of Engineers, 1993-2003. Retired 2003. Responsible for all facility design management, quality control for 200 person engineering organization managing 500-900 million dollars in facilities. Major program engineering supported included the Chemical Stockpile Disposal Program, Ground Based Missile Defense. Army Range and Training Lands Program, FUDS and BRAC Unexploded Ordnance Program, specialized criteria support to the DDESB, and Electronic Security Center of expertise. Programs all required extensive expertise in air blast, fragmentation and Debris, design of facilities to resist accidental explosions. . Served on numerous Army, DoD and joint international technical advisory groups related to Explosives safety, chemical weapons destruction, blast effects and hardened structures:

- Tri-service Committee to update TM 5-1300 Design of Structures to Resist the Effects of Accidental Explosions (1991)
- Tri-service Committee for the Development of Department of Energy Manual for the Prediction of Blast and Fragment Loadings on Structures (DOE TIC 11268)
- Large Rocket Motor Demil R&D Technical Advisory Group support to the Joint Ordnance Commanders Group.
- DoD Technical Advisory Group for the Joint US/Korean Test Program for development of Underground Ammunition Storage Technologies.
- Tri-Services Committee for Department of Energy in the development of hazardous debris prediction methodologies. (DISPRE)
- Visiting Fellow at Army Environmental Policy Institute (AEPI) in support of evaluation of alternative technologies for the destruction of Chemical weapons.
- Recurring support to the DDESB in the update and revision to DoD 6055.9 Std

1988-1993 - Chief of Structures Branch, Civil-Structures Division, U.S. Army Engineer Support Center Huntsville. Responsible for all structural design, in-house and contract in support of Huntsville Center programs. Developed and maintained specialty structural engineering expertise in nuclear and conventional weapons effects, explosives safety, design of hardened structures, missile defense and chemical demilitarization

1981-1986 – Lead Structural Engineer in for the FEMA Key Worker Nuclear Shelter Program. Joint engineering lead with WES Structures Lab in developing new structural technologies to reduce cost of shelters to resist nuclear weapons. Developed a family of shelters which would reduce cost of construction by 20-30 %. Lead Engineer for the Government and contractor team for the facility design and construction of the JACADS and nation wide Chem Demil facilities. Led in-house team of 10-20 personnel in the technical direction and contract quality surveillance of 100-250 man Architect-Engineer design team. 1974- 1981 Structural engineer, Structures Branch, Civil-Structures Division, Engineering Directorate of the U.S. Army Engineer Support Center Huntsville

July 1966- July 1974- Teledyne Brown Engineering – Worked on Apollo, Skylab and Early Shuttle Programs. Performed structural design, stress analysis, vibration testing, development of system test plans and test facility criteria. Special assignment in construction management of top secret intelligence facility in southeast Asia in 1968.

1962-1966 Wayne County Road commission, Detroit Michigan- Co-op student and subsequently field engineer in highway construction program.

**Education:**
Batchelor Of Civil Engineering, University of Detroit, 1965
Master of Science, Systems Engineering, University of Alabama, 1996

**Registrations, Certifications:**
Registered Professional Engineer Alabama, 1972
Certified Protective Design, Civil Defense, 1966
Certified Fallout Shelter Analyst, Civil Defense 1966
Certified Instrument Flight and Ground Instructor, 1980

**Relevant Recent Publications:**
Published over 20 papers, related to blast effects, explosives safety, risk assessment for explosives safety.

## Peer Reviewer – Olaf E. R. "Ross" Heimdahl

**Name:** Olaf E. R. "Ross" Heimdahl
**Address:** Building 31600
Naval Air Warfare Center, China Lake, California, 93555
**Phone:** 760-939-0214
**E-Mail:** olaf.heimdahl@navy.mil

**Present Employer:** NWC China Lake

**Duties or Job:** Mathematician, Detonation Sciences, Code 4T4330D
Modeling and code development

**Highlights:**

NWC Fellow
NATO Insensitive Munitions Workshops, Participant and Instructor
Various TTCCP Action Groups and JANNAF conferences for Propulsion Hazardous

**Education:**

BA in Mathematics and Physics, Luther College, Decorah, Iowa
MA in Mathematics, University of Washington, Seattle, Washington

**Employment:**
Employed since 1970 at China Lake
Began in Propulsion Department in Systems Analysis (guided missile flight-- Sidewinder)
Moved to Research Department in Earth and Planetary Sciences (weather modification)
Most years in Research Department, Detonation Sciences (modeling with early laboratory participation)

**Relevant Recent Publications:**
Published over 100 papers in the areas of: detonation modeling, structural dynamics, warhead penetration and survival, fuel-air explosions, thermal (cook-off) modeling, rocket motor transient behavior, insensitive munitions analysis and design.

# Appendix B: Glossary

## List of Variable Names and Symbols

| Variable | Definition |
|---|---|
| $E_i$ | Individual exposure |
| $P_e$ | Probability of event |
| $P_{f\|e}$ | Probability of fatality given an event |
| $P_f$ | Probability of a fatality |

## Definitions

One of the largest difficulties in risk analyses is clear communications. Often words have many meanings leading to misunderstandings. In this document, the definitions below are used.

Acceptable risk - a predetermined criterion or standard for a maximum risk ceiling.

Accident - that occurrence in a sequence of events that usually produces unintended injury, death or property damage.

Collective risk - the total risk to an exposed population; the expected total number of individuals who will be fatalities. Defined as expected fatalities.

Expected fatalities - the expected number of individuals who will be fatalities from an unexpected event. This risk is expressed with the following notation: 1E-7 = $10^{-7}$ = 1 fatality in ten million person years.

Exposure - the number of times per year an individual is exposed to the potential explosives event.

Hazard - any real or potential condition that can cause injury, illness, or death of personnel or damage to or loss of equipment or property.

Hazardous event - event that causes harm.

Individual risk - the risk to any particular individual, either a worker or a member of the public. A member of the public can be defined either as anybody living at a defined radius from an establishment or somebody following a particular pattern of life.

Maximum individual risk - the highest level of risk to any one person for a given event.

Population at risk - a limited population that may be unique for a specific explosives risk.

Probability of fatality - the likelihood that a person or persons will die from an unexpected event.

Risk - a measure that takes into consideration both the probability of occurrence and the consequence of a hazard. Risk is measured in the same units as the consequence such as number of injuries, fatalities, or dollar loss.

Risk analysis - a detailed examination including risk assessment, risk evaluation, and risk management alternatives, performed to understand the nature of unwanted, negative consequences to human life, health, property, or the environment; an analytical process to provide information regarding undesirable events; the process of quantification of the probabilities and expected consequences for identified risks.

Risk assessment - the process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society, or the environment.

Risk evaluation - a component of risk assessment in which judgments are made about the significance and acceptability of risk.

Safety - relative protection from adverse consequences. In this context, Safety = 1 – Risk.

Scenario – in the SAFER context, a scenario is a set of conditions that are under evaluation. In a scenario, conditions are not static.

Situation – in the SAFER context, a situation is the set of static conditions that are under evaluation similar to a scenario. Static refers to the period of time under evaluation (i.e., one year for SAFER).

Societal risk - the risk to society as a whole (for example, the chance of a large accident causing a defined number of deaths or injuries).

## List of Acronyms

| ACRONYM | DEFINITION |
|---|---|
| ACTA | A small consulting company |
| APT | APT Research Inc. – Developer of SAFER |
| BEC | Blast Effects Computer |
| COTR | Contracting Officer’s Technical Representative |
| DDESB | Department of Defense Explosives Safety Board |
| PDF | Probability Density Function |
| DoD | Department of Defense |
| DTRA | Defense Threat Reduction Agency |
| ERASDAC | Explosive Risk and Structural Damage Assessment Code |
| ES | Exposed Site |
| FACEDAP | Facility and Component Explosive Damage Assessment Program |
| HD | Hazard Division |
| KE | Kinetic Energy |
| MILCON | Military Construction Programming |
| NAS | Network Analysis Schedule |
| NATO | North Atlantic Treaty Organization |
| NEW | Net Explosive Weight |
| NFESC | Naval Facilities Engineering Service Command |
| PDT | Product Development Team |
| PES | Potential Explosive Site |
| PTR | Public Traffic Route |
| Q-D | Quantity-Distance |
| RBESCT | Risk Based Explosives Safety Criteria Team |
| SAFER | Safety Assessment for Explosive Risk |
| SME | Subject Matter Expert |
| T&M | Time & Material Contract |
| TCCR | Transparency, Clarity, Consistency, and Reasonableness |
| V&V | Validation & Verification |
| WBS | Work Breakdown Structure |

## Distribution List

### Internal:

| | | |
|---|---|---|
| 5 | 1176 | Chapman, Leon D., 15312 |
| 5 | 1176 | Cranwell, Robert M., 15312 |
| 1 | 1170 | Skocypec, Russell D., 15310 |
| 5 | 0405 | Jones, Todd R., 12333 |
| 1 | 0492 | Schriner, Heather K., 12232 |
| 1 | 0405 | Fuentes, Marin K., 12333 |
| 1 | 9018 | Central Technical Files, 8945-1 |
| 2 | 0899 | Technical Library, 9616 |

### External:

Alchowiak, Eirc
Hoffman Building 1, Room 856C
2461 Eisenhower Avenue
Alexandria, Virginia 22331-0600
703-644-1412

Chiapello , Thierry
MC, Logistics Div, PM for AMMO
MARCORSYSCOM
2033 Barnett Ave, Suite 315
Quantico, VA 22134-5010
703-432-3170

Coe, COL Donald
Army, HQDA, Attn: DALO-SMA
500 Army Pentagon
Washington, DC 20310
703-693-9956

Covino, Josephine, Dr. (5)
DoD Explosives Safety Board
Room 856C, Hoffman Building I
2461 Eisenhower Avenue
Alexandria, VA 22331-0600
Josephine.Covino@ddesb.osd.mil

Deschambault, Eric
DOD Explosives Safety Board,
Hoffman Building 1, Room 856C
2461 Eisenhower Avenue
Alexandria, Virginia 22331-0600
Eric.Deschambault@ddesb.osd.mil

Eldridge, Richard
USN, CNO (N411B)
2000 Navy Pentagon
Washington, DC 20350-2000
703-604-9915

Hardwick, Meredith (5)
APT Research, Inc
4950 Research Drive
Huntsville, AL 35805
256-327-3380
mhardwick@apt-research.com

Heimdahl, Ross
Naval Air Warfare Center
NWAC Code 4T4330D
China Lake, CA 93555
760-939-0214
olaf.heimdahl@navy.mil

Hogue, Gary (2)
Naval Ordnance Safety and Security Activity
23 Strauss Avenue
Farragut Hall, Bldg. D-323
Indian Head, MD 20640-5035
HogueGA@NAVSEA.NAVY.MIL

King, James "JC"
Dept of the Army
Office of the Asst Secretary (I&E), DASA (ESOH)
110 Army Pentagon (Rm 3D4523)
Washington, DC 20310-0110
703-697-5564

LaHoud , Paul, PE (3)
16210 East Glenn Valley Drive
Athens, AL 35611
Home: 256-232-9121
pl9121@aol.com
Mobile Phone: 256-777-9149

Little, Lyn (2)
USATCES
Risk Management Division (SOSAC-EST)
1 C Tree Road
McAlester, OK 74501-9053
lyn.little@DAC.army.mil

Mazza, Jerry Mazza (MC)
PM for Ammo, MARCORSYSCOM
Barnett Ave, Ste 315
Quantico, VA 22134-5010
703-432-3159

Morrison, George (2)
HQ MARCORSYSCOM-AM-EES
2033 Barnett Avenue, Suite 315
Quantico, Virginia 22134-5010
MorrisonGE@mcsc.usmc.mil

Olson, COL Barry
USAF/SEW
9700 Ave. G, Bldg 24499
Kirtland AFB, NM 87117-5670,
505-846-6059

Olson, Eric (2)
USAF/AFSC/SEW
9700 Ave. G, Bldg 24499
Kirtland AFB, NM 87ll7-5670
505-846-5658
Eric.Olson@kirtland.af.mil

Pfitzer, Tom
4950 Research Drive
Huntsville, AL 35806
256-327-3388
tpfitzer@apt-research.com

Robinson, Brian (2)
United States Coast Guard
Hazardous Material Standard Division, G-MSO-3
2100 Second Street, S.W.
Washington, DC 20593
BRobinson@comdt.uscg.mil

Skudin, CAPT Kemp
CNO (N411)
2000 Navy Pentagon
Washington, DC 20350-2000
703-604-9934

Swisdak, Michael
IHD/NSWC
101 Strauss Avenue
Indian Head, MD 20640-5035
SwisdakMM@ih.navy.mil

Tancreto, Jim
NFESC
1100 23rd Avenue, Building 1100
Port Hueneme, CA  93043
james.tancreto@navy.mil

Tatom, John
4950 Research Drive
Huntsville, AL  35806
256-327-3392
jtatom@apt-research.com

Ward, Jerry M., PhD (2)
DOD Explosives Safety Board,
Hoffman Building 1, Room 856C
2461 Eisenhower Avenue
Alexandria, Virginia  22331-0600
410-465-2342
Jerry.Ward@ddesb.osd.mil

Williams, Ken
USATCES
Risk Management Division (SOSAC-EST)
1 C Tree Road
McAlester, OK 74501-9053
kenyon.williams@us.army.mil

Wright, CAPT William E.
4400 Eaton Place
Alexandria, VA 22310
703-971-3923

Yutmeyer, Pete
4950 Research Drive
Huntsville, AL  35806
256-327-3394
Yutmeyer@apt-research.com